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ENVIRONMENTAL CHALLENGES AND POLICY RECOMMENDATIONS—AN ANALYSIS OF FOUR LARGE CITIES IN THE PEARL RIVER DELTA

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ABSTRACT

The Pearl River Delta is one of the regions with the densest industry and population in the world. Focusing on four large cities in the delta area, Guangzhou, Shenzhen, Foshan and Dongguan, this study presents an in-depth study of environmental challenges of this region based on economic, geographic and pollution data. Economic activities and pollutant concentrations are linked with geographic and remote sensing data to find out the spatial distribution and spatial relationship. It is found that pollution is closely related to local distributions of enterprises, population and road network, water pollution is more serious in coastal cities than inland ones. However, air pollution is more serious in inland large cities. Low-lying land in the delta area should take precautions against the rising sea level, especially for those villages in the city, which are more vulnerable to urban flooding. Policy recommendations, including the use of market mechanisms, strengthening environmental protection, facilitating regional joint action, encouraging low-carbon traveling, pursuing a low-carbon and circular economy, and controlling pollution in rural areas around megacities are given at the end of the paper.

KEYWORDS: Environmental Challenges, Policy Recommendations, The Pearl River Delta & Spatial Analysis

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Original Article

1. INTRODUCTION

Cities are major air, water and solid waste pollution sources in most countries. This is true especially for rapidly growing areas. For example, cities of the Pearl River Delta (PRD) in southern China contributed to 13.1% of China's consumption-based emissions (Qian et al. 2022).Hu et al. (2019) suggested that fast economic growth has negative impacts on the ecosystem. In this study, we focus on four large cities in the Pearl River Delta, Guangzhou, Shenzhen, Foshan and Dongguan (GSFD), each of which has a population of more than 10 million or close to that. In recent years, with the tremendous progress in prevention and control of pollution, and the adjustment of industrial structure and energy structure, the environmental quality of the area has been greatly improved. However, given the unparalleled rapid growth of the economy, the high concentration of industries and the dense population have brought serious environmental pressure to the region. Even after the improvement mentioned above, there is still a significant gap in environmental quality between the region and some famous large cities in developed countries. In addition, due to climate change and low-lying coastal terrain, urban flooding has frequently occurred in the river basin. Therefore, based on economic, geographical and environmental data, this paper attempts to find out the environmental challenges existing in GSFD and put forward relevant policy recommendations.

Pollutants are usually transboundary. Regional environmental regulating and rational land use, transport

and air and water planning can induce benefits including prevention or mitigation of cumulative pollution effects, broader public participation, and improvements to environmental governance (Marsden S., 2011). Zhong et al. (2013) provided a "PRD Approach" that reflects regional cooperative efforts in synchronous air pollutant control to overcome the nation's air pollution challenges. Hence, geographical data and tools are used in this study to examine the region as a whole. Economic activities and concentrations of pollutants are both mapped to find out the spatial relations among cities and to design coordinated and joint policies. Xu et al. (2021) found that the rationalization and upgrading of industrial structures positively affects urbanization quality. Qian et al. (2021) indicated that heavy industry contributes to a major part of emissions. Therefore, in our study, the locations of industrial firms of large scales are carefully matched with points of interest (POI) from geographical sources, to determine their spatial distribution patterns. Urban shapes and sizes (Wang et al., 2019) and transport networks (Che et al., 2011) are also found to have effects on air pollution. Thus, satellite images and road networks are overlapped with other map layers to check their effects. Soil pollution is also discussed in this paper as Pan et al. (2021) pointed out that there is an increasing trend in heavy metal pollution in the area.

In addition, existing studies (Zhang et al., 2021; He et al. 2021) revealed that the inverted U-shaped relationship between city economic development and air pollution, i.e., the environmental Kuznets curve, exists. Lu et al.(2021) found that almost all economic zones in China, except the northwestern economic zone, reached a turning point around 2013. Zhang et al. (2021) further verified that environmental regulation could significantly improve the air pollution situation. All these studies imply that environmental protection policies and abatement instruments can change the pollution trend and cause an inverted U-shaped curve, so policy recommendations in relation to the findings of this study are given at the end of this paper.

In our study, we mainly focus on policies that are tailored for GSFD, based on real situations found either by socioeconomic or geographic analysis or even by field survey, and based on comparison among national or international large cities. To the best of my knowledge, this is the first study that matched the addresses of large-scale factories with POIs and presented the distribution of those factories to study the density of industries. In this way, all environmental challenges mentioned in this paper are derived from facts, not from imagination. In the next section, data sources and methodology are provided, which is followed by results, discussion and policy recommendations.

2. DATA AND METHODOLOGY

2.1 Data

Statistical data used in this study are from the statistical yearbooks of the cities studied. Concentrations of pollutants are sourced from monitoring stations, Atmospheric Composition Analysis Group (Hammer et al., 2020; van Donkelaar et al. 2019) and previous studies of the author (Fu et al. 2020). Data of industrial firms of large scales are from the Chinese Industrial Enterprises Database 2013. Large-scale refers to those enterprises whose main business incomes are more than 20 million Yuan. POIs are from Baidu and Gaode, two popular GPS applications in China. Additional pollution data, which are not presented in the statistical yearbooks, are obtained from the reports of local environmental protection agencies. Satellite images are downloaded from NASA and the Institute of Remote Sensing and Digital Earth (RADI). Road networks are from Open StreetMap.

2.2 Methodology

The methodology used in this paper includes statistical analysis, spatial data process and analysis based on the geographical information system, fuzzy address matching between enterprises and POIs realized with Python, and concentration prediction with geographically weighted spatial regression.

3. RESULTS AND DISCUSSIONS

3.1 Density and Distribution of Industrial Enterprises

The Pearl River Delta is a region with the highest density of industrial enterprises in China. As shown in Table 1, among the top 11 cities with the highest industrial output value per unit land area in China, six are in the Pearl River Delta (Shenzhen, Dongguan, Foshan, Zhongshan, Guangzhou and Zhuhai). These six cities are located along the riverbank of the Pearl River. Among the top 11 cities with the highest number of industrial enterprises per unit land area in China, the Pearl River Delta accounts for four of them. The top three are all cities in the Pearl River Delta. Especially, Shenzhen and Dongguan, ranking first and second, on average, have 3 to 4 large-scale industrial enterprises per square kilometer, which is very dense.

Table1: Top 11 Cities with the Highest Density of Industrial Enterprises

City	GIOV	NUM	GIOV/Area		NUM/Area	
	m Yuan		M Yuan/km2	Rank	Num/km2	Rank
Shenzhen	2729229	7950	1367	1	3.98	1
Dongguan	1469246	7704	597	2	3.13	2
Foshan	2118732	6206	558	3	1.63	4
Shanghai	3307972	8145	522	4	1.28	6
Zhongshan	661480	3212	371	5	1.80	3
Suzhou	3071399	10393	355	6	1.20	8
Wuxi	1435296	5846	310	7	1.26	7
Xiamen	519798	1985	306	8	1.17	9
Changzhou	1209682	4248	277	9	0.97	10
Guangzhou	1957043	4675	263	10	0.63	14
Zhuhai	435338	1170	251	11	0.67	13
Source: Statistical yearbooks 2019 of the cities, except that gross industrial output values are from statistical yearbooks 2017.						

Notes: GIOV means gross industrial output values; NUM denotes the number of large-scale enterprises.

The spatial distribution of large-scale industrial enterprises in Dongguan city is given as an example in Figure 1. It can be found that industrial enterprises are nearly scattered all over the region, except ecological protection zones, farmland protection zones and central urban areas. The distribution does not show any significant patterns, except for some industries with a small number of enterprises. For example, the pharmaceutical manufacturing industry is mainly sitting along the Dongjiang River, a tributary of the Pearl River. The oil processing industry is mainly located along the trunk of the Pearl River. This implies that the location selection of industrial enterprises is not only affected by city planning (with patterns), but also by various factors (lack clear patterns) such as operation cost, supply chain, characteristics of production factors, market, environmental regulation and the efficiency of the local government. Cost and production factors should be of the most importance for entrepreneurs. Therefore, it is the pursuit of low cost and high production efficiency that leads to the high density of industrial enterprises in PRD, which has a great impact on the water quality and air quality of the region. In addition, the intertwined industrial zones and residential zones also cause troubles for both sides.

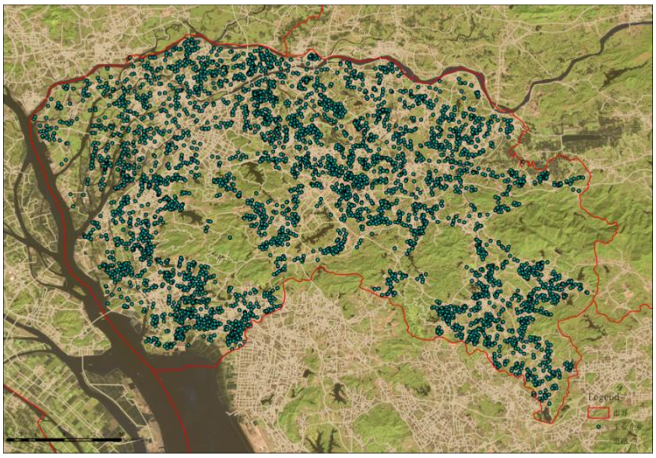

Figure 1: Distribution of Large-Scale Industrial Enterprises in Dongguan City.

Source: By matching Chinese industrial enterprise database and POIs and mapping the results.

3.2 Air Pollution and Spatial Distribution of Concentration

As a result of pollution control, energy replacement, boiler regulation, promotion of new energy vehicles, vehicle registration and traffic restrictions, as well as the application of new management mechanisms and technologies such as emission permission and remote monitoring of the emission, the concentrations of air pollutants have decreased. For example, in recent years, the annual average concentration of PM2.5 in GSFD has been lower than 36 µg/m3. However, the number of days with good air quality decreased (see Table 2 for data in 2018). This is because the decrease in concentration is relatively small. When large rebounds occur, the atmospheric quality indices of those days are worsened. Considering the high density of industrial enterprises and population, it is difficult for GSFD to achieve the same air quality levels as in New York, London and Tokyo, where the tertiary industry plays a key role in the economy.

Table 2: Comparison of Environmental Quality between GSFD and Other Cities (2018)

City	PM2.5 CON	DGAQ	IWDI	GPSPC	GCRBUA	CSTR
	µg/m3	Day per year	K tonnes /km2	m2/person	%	%
Changzhou	53	239	28	12	43	90
Beijing	51	227	5	16	48	93
Wuxi	43	258	45	15	43	97
Suzhou	42	269	46	14	42	96
Shanghai	36	296	46	8	39	95
Dongguan	36	301	79	24	47	95
Guangzhou	35	294	19	17	45	96
Foshan	35	293	41	17	44	95
Zhongshan	30	312	39	6	15	100
Zhuhai	27	325	25	20	50	97
Shenzhen	26	345	39	15	45	97
Xiamen	25	360	138	15	45	94
Hong Kong	26	-	-	-	-	70
Singapore	20	-	-	25	50	100
New York	14	-	-	31	24	100
London	13	-	-	23	40	100
Tokyo	13	-	-	14	43	-

Notes: The same data sources as Table-1. This table is ordered by the concentration of PM2.5. PM2.5 CON means annual average concentration of PM2.5. DGAQ stands for days with good air quality. IWDI denotes industrial wastewater discharge intensity. GPSPC means green park space per capita. GCRBUA stands for green coverage rate of built-up area. CSTR denotes a centralized sewage treatment rate.

Figure 2 shows the distribution of PM2.5 annual average concentration in the Pearl River Delta. It is found that the pollution in the coastal areas of the Pearl River Delta is relatively low, and the pollution in the eastern part of the river is generally lower than that in the western part. The heavily polluted area is located at the junction of Guangzhou and Foshan. Concentration changes of PM2.5 from 2012 to 2017 are shown in Figure 3. Red and yellow indicate increased pollution and green indicates reduced pollution. Figure 3 also presents road networks. It can be seen that the road networks basically overlap with the heavily polluted areas. The pollution of nitrogen oxides (NOx) is closely related to the road networks, because roads connect factories, dense residential areas, which are sources of pollution, and traffic itself is also a major pollution source.

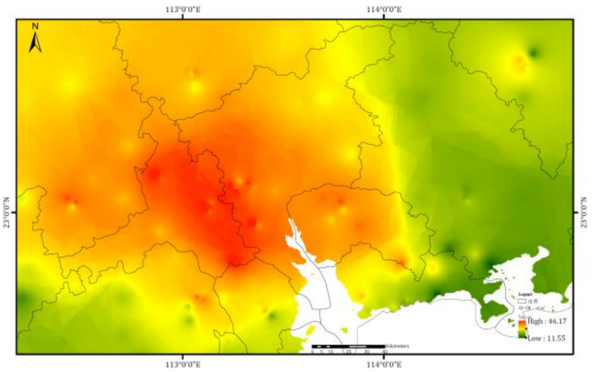

Figure2: Distribution of PM2.5 Annual Average Concentration in the Pearl River Delta(2015).

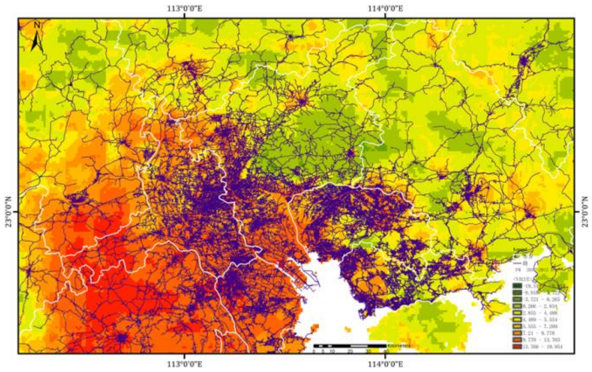

Figure3: Road Networks and Changes of PM2.5 Annual Average Concentrations from 2012 to 2017.

Figure 3 also shows the impact of meteorological and geographical conditions on air pollution. For example, at the bottom left of Figure 3, where the road network is sparse, and the pollutant concentration (in Figure 2) is low. However, the increment of the concentration is large, mainly because the northeast wind in winter brings pollutants from large cities in the center of the map, and the precipitation drops in winter. This implies that the diffusion of pollutants is an important factor affecting the pollution level.

3.3 Challenges from Water Pollution

Papermaking, leather, textile, printing and dyeing and chemical industries are major sources of water pollution in the Pearl River Delta. Due to the dense population, sewerage and agricultural irrigation are also the main sources of water pollution. In recent years, GSFD has made great efforts to control black and smelly water bodies, implemented rainwater and sewage diversion and sewage treatment, controlled the discharge of industrial and agricultural sources and carried out drainage permit management, which have significantly improved the water quality. In contrast with air pollution, the water quality of inland cities is better than that of coastal cities, i.e., the water pollution in Dongguan and Shenzhen is more serious than that in Guangzhou and Foshan. From the perspective of the whole province, the inland cities, Heyuan and Zhaoqing, have the best water quality. Similar situation exists nationwide. This is because water pollution enterprises are usually sitting in areas close to water. Thus, there is great pressure to meet the standards in water pollution control for GSFD. As the local

economic growth is closely related to the profitability of enterprises, management of industrial wastewater discharge is more sensitive than the treatment of domestic sewage, partially due to local protectionism.

3.4 Pressure Caused by the Rapid Growth of Domestic Waste

The population of the four cities in the Pearl River Delta grew rapidly. For example, the number of permanent residents of Guangzhou increased by 421000, 542000, 455000 and 406000 respectively from 2015 to 2018, with a total increase of 1824000 in four years. Shenzhen has increased by 2.248 million in these four years. Accordingly, in recent years, the weight of domestic waste removal in Guangzhou and Shenzhen has increased by about 500000 tonnes and 600000 tonnes per year, with growth rates of about 8% and 13%, respectively. The average annual growth rate of domestic waste is 8% in Foshan, and 5% in Dongguan. As the landfill tends to be fully loaded and the urban land space is very limited, these four cities have been building up more and more waste incinerators. In spite of those efforts, the existing solid waste disposal capacity can hardly meet the demand. In addition, medical waste and hazardous waste disposal facilities are relatively old and insufficient, and construction waste is difficult to be disposed of locally.

3.5 Climate Change and Urban Flooding

Due to climate change and urban buildings which block the natural drainage channels and weaken the storage capacity of natural water bodies, continuous heavy precipitation from March to September usually causes urban flooding in low-lying areas. Urban flooding generally does not occur in old urban areas, but in new urban areas that are close to rivers. This is because the traditional parts of the city have been tested and adjusted for hundreds of years. Some of the new urban areas, however, often occupy the original surface drainage channels or even sit on the overflow buffers of the river. This is extremely worsened in "villages in the city", where planning is insufficient and buildings are nearly piled up together (handshake buildings). Congestion can also happen in underground drainage facilities because of narrow pipelines and aging structures. In case of typhoons and heavy rains, urban flooding is easy to occur in those places. For example, on May 21, 2020, residential areas and roads in the red parallelogram area in Figure 4 were flooded. The purple areas in Figure 4 are areas with an altitude lower than two meters above sea level. It can be seen that most of these areas are densely populated. In consideration of global warming which may lead to the rising of the sea level, those areas should take precautions against this.

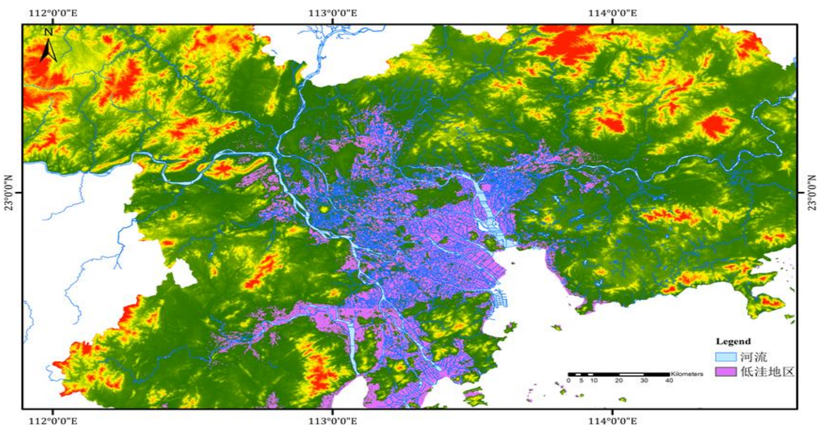

Figure 4: Low Lying Areas in the Pearl River Delta (purple Areas).

Source: Calculated based on SRTM.

4. POLICY RECOMMENDATIONS

4.1 Use of the Market Mechanism in Environmental Protection

Production factors and resources should be allocated, and external costs of pollution should be internalized based on market mechanisms. First, the land use planning should be reviewed to strengthen the requirements of ecological and environmental protection, so that the enterprises can fully consider the external costs, and treat the land and other production factors with caution. Second, rationalize pollution taxes and resource taxes on water and energy consumption, and implement a progressive pricing system for water resources. It is suggested to levy a carbon tax on enterprises that use coal as energy (except thermal power plants and large steel plants) to promote energy upgrading. Third, encourage social capital to invest in the field of environmental management. Fourth, encourage policy banks and other financial institutions to support environmental protection, circular economy, atmospheric monitoring, tail gas treatment, sewage treatment, water resource conservation, and utilization of clean and renewable energy, and restrict loans to enterprises which violate environmental laws.

4.2 Strengthen the Protection of the Environment

With regard to air pollution prevention and control, PM2.5, nitrogen dioxide and ozone have become the main factors that affect the continuous improvement of air quality, and the main pollutants that damage human health. Nitrogen dioxides mainly come from mobile sources such as motor vehicles. It is suggested to carry out the coordinated control of PM2.5 and ozone, identify pollution sources and prepare a list of instruments for emergency emission reduction, promote the electrification of logistics distribution vehicles, continue to carry out pollution control of diesel trucks, ships and construction machinery, reduce the emission of volatile organic compounds, and realize the negative growth of coal consumption.

As for water pollution prevention and control, it is suggested to strengthen supervision, coordination, environmental law enforcement, water quality monitoring and the ability for early warning; Strive to eliminate the inferior class V polluted water as soon as possible; Coordinate with surrounding cities to implement joint prevention and treatment of water pollution and to improve water quality from upstream.

In terms of solid waste prevention and control, it is suggested to accelerate the construction of waste treatment facilities and further promote the classification of domestic garbage. Improve the disposal capacity for hazardous waste treatment, and improve the supervision and management capacity by using information technologies such as GPS, GIS and big data.

4.3. Regional Joint Prevention and Treatment of Air and Water Pollution

It is suggested to set up regional environmental protection planning, create joint prevention and treatment system and establish an institution responsible for unified coordination and implementation of policies, and organize a regional professional association to provide advice for the overall region. Total emission of atmospheric and water pollutants should be controlled for the delta region, and the information sharing platform should be established to facilitate the exchange and cooperation between cities.

4.4. Encourage Low-Carbon Travelling

Bicycle lanes should be planned in the new built-up areas, and should be restored in central urban areas where space allows, to encourage cycling. Optimize the pedestrian passages on both sides of urban roads, plant green belts to isolate vehicle exhaust and noise, set up more pedestrian overpasses, remove unnecessary fences, create open space on the ground floor of large buildings to shorten walking distances, provide rest stations for pedestrians, and construct a pedestrian-friendly urban road environment. Encourage students to go to school in walking school buses. Encourage carpooling, establish carpooling websites, and encourage the use of public transportation.

4.5 Pursuing a Low-carbon and Circular Economy

Promote the low-carbon transformation of traditional manufacturing industry, strengthen the R&D and application of low-carbon products, and encourage technology innovation. Set emission reduction targets and carry out low-carbon pilot projects such as low-carbon government, low-carbon enterprises, low-carbon communities, low-carbon finance, energy-saving buildings, low-carbon consumption and low-carbon lifestyle. At the same time, set up evaluation systems for those low-carbon developments. Promote the use of new energy buses, taxis and private cars, and accelerate the construction of supporting infrastructure such as charging stations. Improve energy efficiency, and gradually transfer to renewable energy and cleaner fuels. Develop a circular economy and encourage recycling, so as to reduce resource consumption and solid waste. The reuse rate of urban water in the Pearl River Delta is about 72%, which is lower than the national average of 80%. Therefore, it is suggested to design ab urban rain collection system, promote the use of reclaimed water, and preserve urban water sources.

4.6 Strengthen Pollution Control in Rural Areas around Mega Cities

Adjust the structure and layout of the planting industry, encourage the use of organic fertilizers, and reduce the use of chemical fertilizers and pesticides. Control the pollution from livestock farming, and scientifically delimit prohibited and restricted areas for livestock farming. Assist villagers in building an urbanized water supply, drainage and toilet system, accelerate the construction of domestic waste and sewage treatment facilities, and improve the effective treatment rate of rural domestic wastes. Promote the treatment and restoration of polluted cultivated land around cities. As for heavily polluted cultivated land, it is suggested to implement planting structural adjustment or restore farmland to forest or grassland. Assess the environmental risk for those polluted land that threatens the safety of groundwater and drinking water sources. Encourage social capital to invest in rural soil pollution control and remediation by increasing the government's purchase of soil pollution control services.

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